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WATER RECLAMATION STUDY PROGRAM. RECLAMATION OF REUSABLE WATER FROM SEWAGE

George E. Bennett, et al

Stanford University
Stanford, California

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PROGRESS REPORT

WATER RECLAMATION STUDY PROGRAM

DEMONSTRATION PROJECT GRANT

NO. WPD 21-04

George E. Bennett, Rolf Eliassen, and Perry L. McCarty
Water Quality Control Laboratory
Department of Civil Engineering
Stanford University
Stanford, California

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RECLAMATION OF REUSABLE WATER FROM SEWAGE
DEMONSTRATION PROJECT GRANT NO. WPD-21-04

SUMMARY STATEMENT

A demonstration plant for the removal of nutrients from activated sludge effluent has been operated by Stanford University. The plant flow rate varies from 8.5 to 10 gpm. Nutrient removals of up to 93.7 percent for phosphate and 92 percent for nitrate have been achieved, using ion-exchange techniques preceded by filtration. Despite the fact that a gradual loss of resin capacity occurs due to organic and physical fouling, it has been possible to achieve long-term average phosphorous removal of 85.7 percent (average effluent phosphorous concentration of 0.84 mg/l), and nitrate nitrogen removal of 79.1 percent (0.73 mg/l average effluent concentration). Essentially complete restoration of fouled resin capacity has been achieved as a normal part of the plant operation, using an acid-methanol restoration treatment.

During the past eleven months, significant accomplishments have included (1) the redesign of filtration and ion-exchange equipment and replacement of the original equipment with optimized units, (2) successful plant-scale restoration of the ion-exchange resin (twice), (3) increase of the filtration unit and ion-exchange flow rates (thereby reducing capital equipment costs), (4) successful preliminary testing relative to reductions in operating chemical costs, (5) demonstration of the effects of non-nutrient anions in the water to be processed, (6) initiation of a detailed investigation of the key parameters for achieving satisfactory filtration of activated sludge effluents and, (7) evaluation of the influence of trace nutrient materials (i.e., materials other than phosphorous and nitrates) upon algal growth potential.

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INTRODUCTION

Present emphasis upon water quality control and prevention of all types of water pollution makes it obvious that traditional "complete" treatment of sewage via activated sludge or trickling filter plants can no longer be considered the ultimate in wastewater treatment. There is increasing concern over eutrophication of lakes and large bodies of water, due to a heightened awareness of the significance of the more subtle forms of pollution. "Pollution" in the past has referred generally to nuisance conditions. In the modern context, we have broadened the application of the term to include any meaningful deterioration of the natural quality of streams, rivers, and lakes. The result of this broadened definition of pollution is that the quality demands placed upon sewage treatment effluents have become more stringent, and will continue to do so. Present attention is being concentrated mostly in the area of the "nutrient problem," primarily because of present and potential problems involving algae and algal blooms.

Algae present a peculiarly insidious threat to water quality, since algal growth represents the conversion of stable inorganic materials into organic (and therefore potentially putrescible) matter. The problem is further compounded by the fact that the decay of dead algae can cause unique taste and odor problems, in addition to contributing to the traditional pollution problem of oxygen depletion. The recent widespread interest in and concern about these problems is certainly justified, but it would appear that certain attitudes are developing which are a bit out of focus. The present sharp focus of attention upon algae and algal problems has tended to obscure the fact that the presence of algae in natural waters is (except in some special cases) normal and that algae are a traditional part of the natural ecology and balance of nature. Algae <u>can</u> present significant problems, but the mere presence of algae in a lake or river does not mean that algae problems exist. The attitude that algae cause problems and that algae therefore ought to be eliminated from natural waters is at best a grievous oversimplification. Algae should be considered in terms of the problems which they <u>may</u> create; our purpose should be to eliminate <u>algal problems</u>, not to eliminate algae per se.

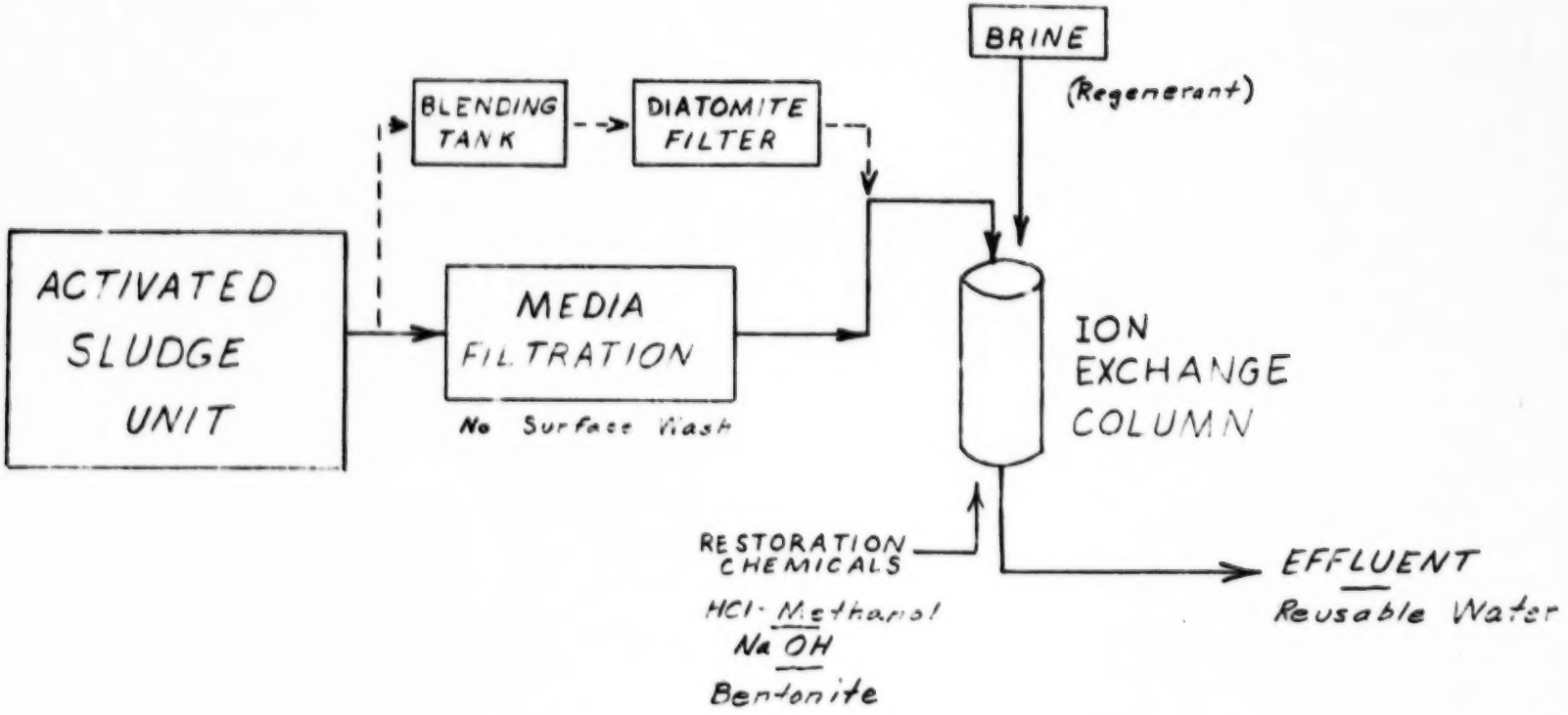
Control of inorganic nutrient materials, particularly phosphorous and nitrogen, appears to be a most promising means of controlling algae problems. The reduction of the phosphorous and nitrogen content of natural waters will reduce or eliminate algal blooms, and it is algal blooms which cause pollution problems. Sewage effluents are rich in both phosphorous and nitrogen, and much attention has been focused upon sewage effluents as a cause of the increasing number of algal bloom problems. A recently completed Task Force report sponsored by the American Water Works Association indicates that the question of nutrient enrichment by sewage effluents has perhaps been overemphasized in relation to other sources of nutrients, particularly agricultural fertilization. Nevertheless, it is logical to approach the problem of algal bloom elimination by limiting the amounts of phosphorous and nitrogen in sewage effluents.

STATEMENT OF OBJECTIVE

Anion exchange treatment and filtration treatment both offer some obvious benefits in the conversion of sewage treatment effluent to reusable water. Broadly stated, the objectives of the demonstration plant operation are to investigate and define the potential benefits, particular advantages and disadvantages, and general applicability of ion-exchange and/or filtration for wastewater reclamation. Both ion-exchange and filtration are viewed as available tools for improving water quality. While ion-exchange produces a greater degree of improvement of water quality, the filtration process parameters are also of great significance, by virtue of the fact that most types of tertiary or advanced waste treatment and water renovation systems will involve filtration.

It is apparent to those familiar with water renovation that many types of treatment (reverse osmosis, chemical precipitation, carbon adsorption, etc.) methods can be used to reclaim wastewaters. It is equally clear that none of the processes presently under study is a panacea. The reasons of course are that each process has particular strengths and particular weaknesses, and that the various requirements of water "renovation" vary with the particular situation at hand in any given case. Activated carbon treatment, for example, affords high COD removal, but does not reduce the phosphorous or nitrogen content. Chemical precipitation, on the other hand, can produce good removal of phosphorous, but will not remove nitrogen compounds. The present task in the field of water renovation is the development of a complete technology of treatment methods. Researchers should in effect provide a "catalogue" of the tools available, so that design engineers will be able to select the most appropriate and economical process to use for any individual situation. Such a "catalogue" must contain factual and proven information as to advantages and disadvantages of each type of treatment. Until we are able to select the optimum process for the particular situation, water renovation technology must be considered incomplete. With this idea in mind, the Stanford water reclamation project is being operated in such a way as to hopefully discover

all pertinent advantages and disadvantages of filtration-ion exchange treatment. It is important to define the scope of the benefits peculiar to a filtration- ion exchange system so that full use can be made of this treatment method; it is equally important to establish what the limitations of the process are, in order to present its misuse, or blind application, without regard to the particular situation existing.



ORIGINAL DEMONSTRATION PLANT FLOW SHEET

Figure One

DEMONSTRATION PLANT

The available equipment and the flow sheet of the 10 gpm demonstration plant at the beginning of the period covered by this report are indicated by Figure One. The equipment included the following:

A. Activated Sludge Unit

The activated sludge unit is a pre-assembled "Rapid-Bloc" type unit, provided by the Chicago Pump Co., Hydrodynamics Division, FMC Corporation. The unit consists of an aeration chamber, a settling tank, and an aerobic digestion compartment. It is operated as a secondary treatment unit, with an overall (aeration tank plus settling tank) theoretical detention time of 5.9 hours at the 10 gpm flow rate. The aerobic digestion compartment capacity is 295 cubic feet. A comminutor is included, although the unit normally receives settled sewage (i.e., the effluent from the Palo Alto Sewage Treatment Plant primary settling tanks) as the influent liquid.

B. Original Sand Filter

The original sand filter was a pressure type filter with a surface area of 9.62 square feet (i.e., 3.5 feet in diameter). The filter had a gravel underdrain system and utilized a 24-inch depth of sand. The sand had an effective size of 0.54 mm and a uniformity coefficient of 1.37. The filter had no provision for surface-wash. At the normal plant flow rate of 10 gpm, the filtration rate was approximately 1.08 gallons per minute per square foot of sand surface area.

C. Diatomite Filter

The diatomaceous earth filter had a total septum area of 5.5 square feet. The rate of body feed was controlled by a manually-set device to give a constant amount of body feed

regardless of the cake differential pressure. The filter utilized a compressed air "bump" type of backwash. Hi-Flo Super Cel diatomaceous earth was used for filtration. The diatomite filter was provided by the Filtration Systems Division of DeLaval Turbine, Inc., and diatomaceous earth was supplied by the Johns-Manville Company.

D. Original Ion-Exchange Column

The original ion-exchange column was 2 feet in diameter and contained a thirty and one-half inch depth of resin providing a total resin volume of slightly less than 8 cubic feet (1 bed volume = 60 gallons). The resin was supported by a 14-inch depth of sand and gravel which provided distribution of the backwash water flow. The maximum available freeboard for resin bed expansion during backwashing was 21 inches, allowing a resin bed expansion of about 69 percent.

E. Ion-Exchange Resin

Duolite A-102D, a strong base anion exchange resin with quaternary ammonium functional groups is the type of ion-exchange resin used. This resin is supplied in porous bead form and is operated on the chloride cycle (i.e., brine is used for regeneration). The resin was supplied by the Western Division of the Diamond Alkali Company, Redwood City, California. Duolite A-102D was selected as the ion-exchange resin on the basis of laboratory work in which a number of types and varieties of ion-exchange resins were tested.

F. Observation Pond

The observation pond has a maximum depth of four and one-half feet and an overall capacity of approximately 250,000 gallons. The purpose of the pond is to serve as a holding pond for the renovation treatment effluent water. The effect of the nutrient removals resulting from filtration-ion exchange treatment can be evaluated under natural conditions of sunlight and

temperature, and the elimination of algal blooms and effect on algae growth in general can be demonstrated. The pond also provides information relative to bacterial and virus populations in the finished water.

Some difficulties had previously been experienced with seepage, and it was also felt that nutrients may have been "leached out" of the underlying soil. To eliminate these uncertainties it was decided to line the pond, provided an effective and economical liner material could be obtained. A liner was obtained on a loan basis from the Griffolyn Co., Inc. of Houston Texas, and it has proved to be extremely durable and resistant to punctures, tears, and light exposure problems.

G. Replacement of Sand Filter

For reasons which are discussed later in this report, the original sand filter was replaced in early 1966. The replacement filter was fabricated and supplied by the Eimco Filter Corporation of Salt Lake City, Utah. The filter can be operated under either pressure or gravity conditions. No gravel is used for support of the filtration media; instead, 21 plastic-and-nylon "Spraying Fulljet" media supports are used which provide a very uniform backwash water distribution. Air agitation of the media for 10-20 minutes is done immediately prior to backwashing the filter. The air agitation serves the same purpose as a water "surface wash," and has thus far prevented the formation of mudballs, or the accumulation of foreign matter in the filter. Viewing ports were provided so that the condition of the sand can be readily observed. The replacement filter is 3 feet in diameter and operates at a flow rate of about 1.4 gallons per minute per square foot of surface area. The filter is backwashed at a flow rate of 125 gpm, producing a rise rate of 28.5 ins per minute. The filter media presently in use is sand. The characteristics of sand filter media include

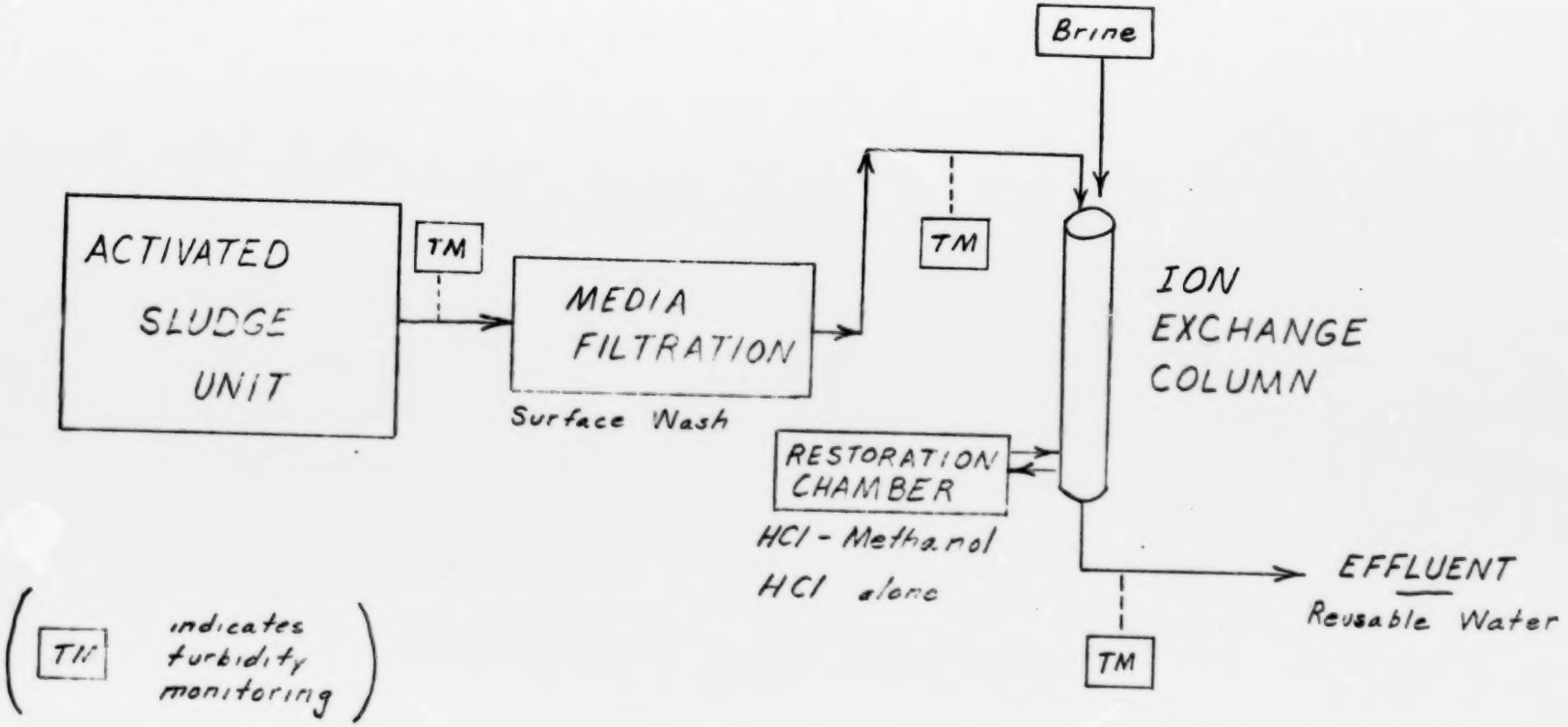
an effective size of 0.52 mm and a uniformity coefficient of 1.48.

H. Replacement of Ion-Exchange Column

The original ion-exchange column was also replaced in early 1966, due to design shortcomings which are discussed later in this report. The replacement ion-exchange column was fabricated and provided by the California Filter Co., of Burlingame, California. The features incorporated into the replacement column were designed to eliminate the operational difficulties and uncertainties which had been encountered with the original column. Major improvements made included (1) elimination of the sand-gravel support bed through the use of specially designed underdrain appurtenances, (2) changes in the resin depth-to-area ratio and the resultant reduction of the volume of resin required (the redesign, by assuring better distribution of influent water, allowed the use of a flow rate of 26 bed volumes per minute instead of the 10 BV per minute rate used in the original column), (3) provision of adequate freeboard for resin expansion (up to 113 percent) during backwashing, (4) provision of viewing ports to permit observation of resin under normal flow, backwash and regeneration conditions, and (5) incorporation of a restoration chamber as an inherent part of the ion-exchange equipment.

I. Revised Flow Sheet

The revised sequence of operations presently in use is indicated by the flow sheet shown on Figure Two.



REVISED DEMONSTRATION PLANT FLOW SHEET

Figure Two

OPERATION PLAN

The basic operational process sequence at the Demonstration Plant at present is indicated by the flow diagram on Figure Two. Pre-filtered activated sludge effluent is applied to the ion-exchange column until a total of 180 BV have been passed through the column. At this point, the nutrient and other anions in the applied activated sludge effluent have displaced the original chloride ions of the resin and most of the exchange "sites" of the resin are occupied by anions which have been removed from the applied activated sludge effluent. Also, some of the particulate matter which was not removed by prefiltration has collected on the resin surface. In order to prevent "breakthrough" of the nutrient and other anions, the ion-exchange resin must be regenerated. The first step in the regeneration procedure is the backwashing of the resin to remove any particulate matter which has accumulated at the resin bed surface. Essentially complete removal of accumulated matter can be achieved by using a uniformly-distributed backwash flow sufficient to produce a resin bed expansion of 50-55 percent. For reasons of backwash water use economy and for backwash efficiency, it is imperative that good distribution of the backwash water is achieved. The actual regeneration process consists of applying a 10-12 percent solution of salt brine. In this high chloride situation, the removed anions are re-exchanged for chloride ions in accordance with the Law of Mass Action. The final step in the regeneration procedures is down-flow rinsing of the resin to remove excess brine. Normal operation therefore consists of processing 180 BV of activated sludge effluent, followed by (1) backwashing of the resin to remove accumulated particulate matter, (2) regeneration of the resin with a brine solution, and (3) a rinse to remove excess chlorides before putting the column back on line. There is, however, another periodic resin treatment process involved in economical ion-exchange renovation of wastewater, the restoration treatment.

A characteristic of the anion exchange process in treating activated sludge effluent is a gradual loss of exchange capacity. This loss of capacity is due to organic and physical fouling of the resin. Organic

fouling involves the ability of the resin to remove negatively charged organic molecules, as well as anions. This property is beneficial, since ABS and COD reduction are thereby achieved. However, some of the removed organics are not re-exchanged during resin regeneration as efficiently as are the inorganic anions. They therefore slowly accumulate, contributing to resin fouling. It has been established by laboratory work that essentially complete removal of these organic foulants can be achieved by occasional treatment of the resin with an organic solvent. Methanol is the solvent which has been used, due to its efficiency and the fact that it is the cheapest available organic solvent. The physical fouling refers to the accumulation of extraneous particulate matter in the resin over a period of time. This may occur only very gradually if proper resin backwashing is provided, but complete removal of particulate matter after each 180 BV ion-exchange "run" is not feasible, due to the amount of backwash water and time which would be involved. Instead, the very slight gradual accumulation of foreign matter is allowed to occur over a period of time until resin efficiency seems to be affected. The extraneous material is then removed from the resin by means of a 4.0 normal hydrochloric acid bath. Up until the present time, the acid and methanol have been used simultaneously in a single solution, with the process referred to as resin restoration. Field experience has indicated that significant economics may possibly be achieved by using acid and methanol treatments separately, according to the relative degree of physical and organic fouling. The economics referred to, of course, involve the relative costs of hydrochloric acid (1.45 cents per gallon for 4.0 N HCl) and methanol (30 cents per gallon). The economics of restoration are referred to in greater detail elsewhere in this report. The ability to restore the operational capacity of the resin after fouling occurs is a key factor in ion-exchange renovation of wastewater, since it is prohibitively expensive to replace fouled resin with fresh resin.

To summarize, activated sludge effluent is processed in 180 BV quantities with the resin regenerated after each 180 BV run. The resin is given a restoration treatment whenever the resin becomes physically or organically fouled to a degree which significantly reduces the overall anion removal capacity.

GENERAL RESULTS AND CONCLUSIONS

A. Ion-Exchange Efficiency

At the beginning of the period covered by this report, the first resin restoration treatment (using 5 BV of 4.0 N HCl and 5 BV of methanol) had just been completed. The original sand filter and original ion-exchange column were then used to process 5500 BV of activated sludge effluent. Tables One and Two illustrate the fact that the field results were not consistent with the laboratory experience. Table Three illustrates the rate of loss of resin capacity and the inconsistency of the overall treatment.

TABLE ONE

PREDICTED DEMONSTRATION PLANT PERFORMANCE--BASED ON LABORATORY RESULTS

	For 6000 BV		For 10000 BV	
	Average Effluent Conc.	Average Removal	Average Effluent Conc.	Average Removal
Phosphorous	0.4	95%	1.2	85%
NO_3	2.0	90%	4.0	80%
ABS	0.25	80%	0.5	60%
COD	20	50%	30	25%

TABLE TWO

DEMONSTRATION PLANT ION-EXCHANGE PERFORMANCE DURING FIRST 5500 BV PROCESSED AFTER FIRST RESIN RESTORATION-- USING ORIGINAL ION-EXCHANGE COLUMN AND ORIGINAL SAND FILTER

	Overall Results for 5500 BV	
	Average Effluent Conc.	Average Removal
P	2.2 mg/l	60%
NO_3	1.3 mg/l	72%
ABS	0.6 mg/l	40%
COD	25 mg/l	22%

It was felt that equipment design shortcomings were responsible for the inferior performance. Detailed studies of the filtration equipment and the ion-exchange column were made, and a decision was made to replace the sand filter and the ion-exchange column, and to discontinue the use of diatomite filter (the equipment performance studies and conclusions relative to diatomite filtration are described later in this report)

The ion-exchange column was replaced first, and 1000 BV were treated in the course of working out the details of column operation. When satisfactory operating techniques were established, the resin was given a restoration treatment. Figures Three and Four indicate the resin capacity recovery produced by the acid-methanol restoration treatment.

TABLE THREE

TYPICAL RESULTS OBTAINED DURING THE PROCESSING OF 5500 BV IMMEDIATELY FOLLOWING THE FIRST RESTORATION TREATMENT

Total BV Processed After Restoration	Effluent P (mg/l)	P Reduction Percent	Effluent NO_3 (mg/l)	NO_3 Reduction Percent
170	0.7	87%	0.1	97%
1000	2.2	66%	3.9	-
1440	1.6	80%	-	-
1620	2.0	69%	3.0	80%
1800	1.6	74%	5.8	24%
2200	2.1	63%	4.5	34%
2550	2.6	60%	0.3	85%
2900	3.7	51%	1.2	80%
3450	2.0	65%	0.5	83%
3750	5.2	16%	1.3	13%
4100	4.0	29%	1.0	55%
4500	1.8	78%	-	-
4950	1.1	76%	0.2	88%
5250	2.0	58%	0.2	90%
5500	1.9	66%	0.1	90%

RESIN EFFICIENCY BEFORE SECOND RESTORATION

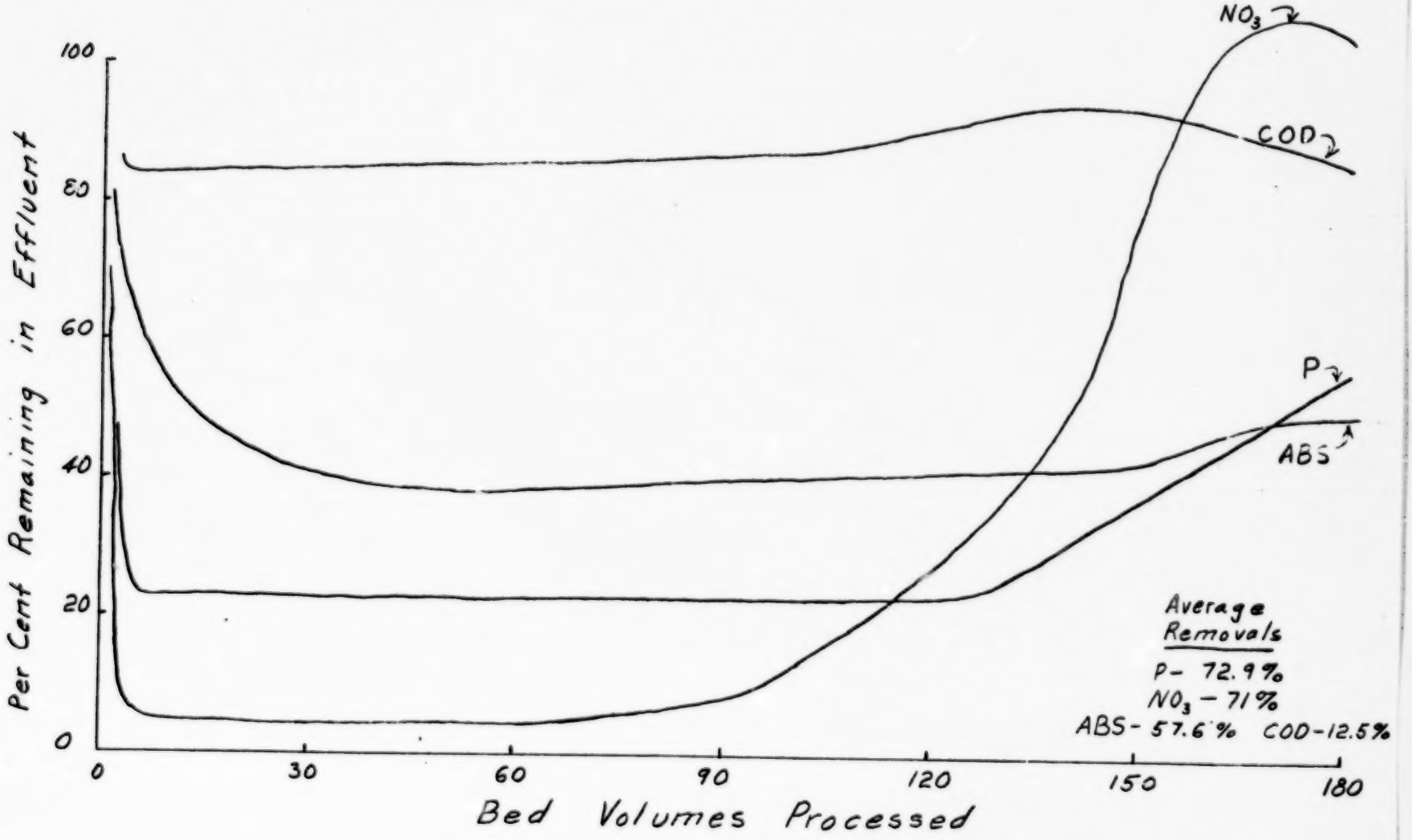


Figure Three

RESIN EFFICIENCY AFTER SECOND RESTORATION

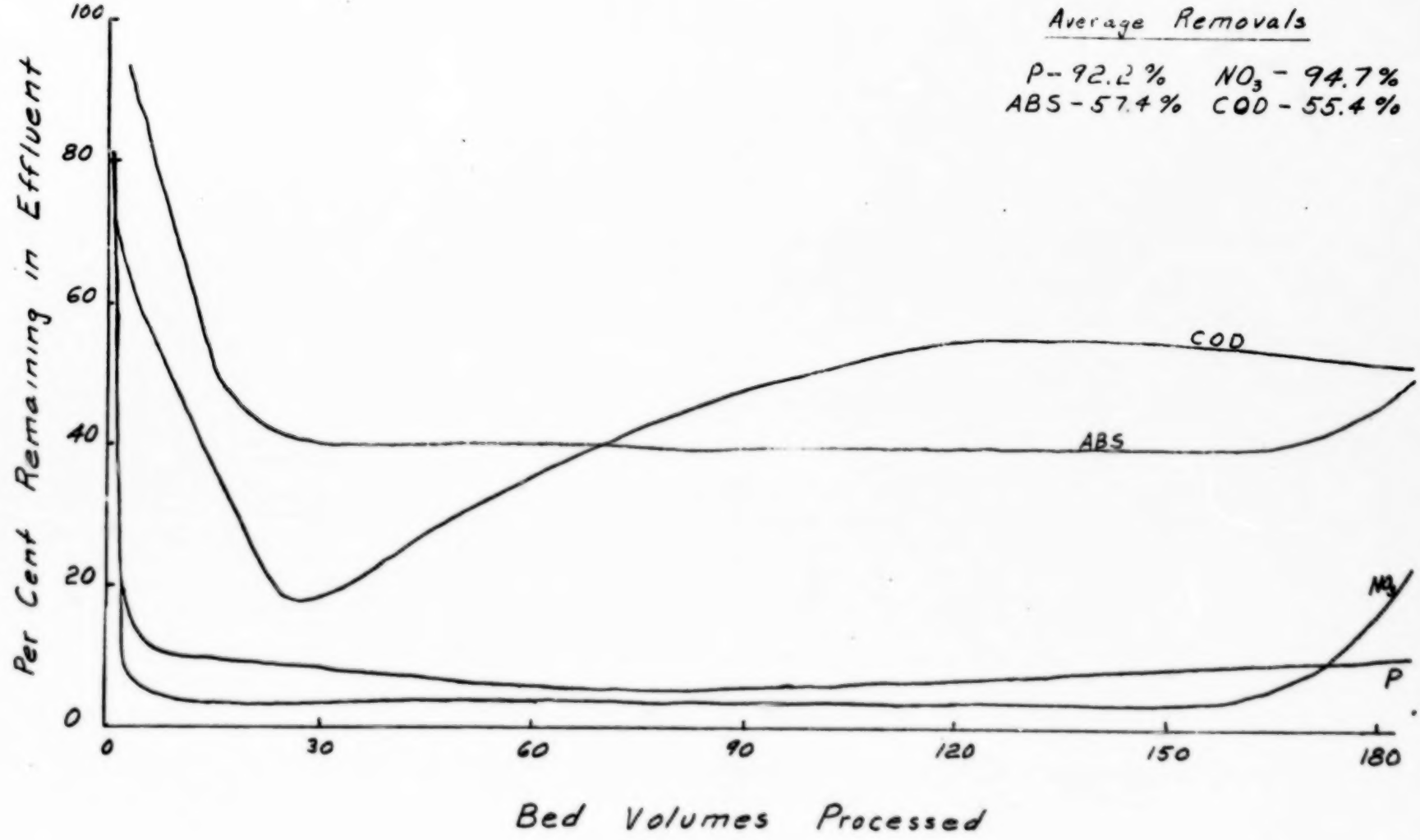


Figure Four

Table Four indicates the resin removal efficiencies for the first 2500 BV processed using the replacement ion-exchange column preceded by the original sand filter. Table Five compares the system performance with the comparable period after the first restoration treatment when the original ion-exchange and original sand filter were in operation. It can be seen from Table Five that phosphorous removal efficiency increased from 63.6 percent to 83 percent after the improved ion-exchange column was put into operation.

TABLE FOUR

OPERATION DURING FIRST 2500 BV AFTER SECOND RESTORATION

NEW IEC AND OLD SAND FILTER

	Overall for 2500 BV		For Individual Runs	
	Average Effluent Conc.	Average Removal	Maximum Removal	Minimum Removal
P	1.37 mg/l	83.2%	92.8%	72.4%
NO_3	0.23 mg/l	60.4%	92 %	19 %
ABS	0.22 mg/l	67.5%	86 %	43 %
COD	36.6 mg/l	48 %	84 %	18 %

TABLE FIVE

	Initial 2500 BV processed after first restoration, using original sand filter and original ion-exchange column.	Initial 2500 BV processed after second restoration, using original sand filter and replacement ion-exchange column.
Average P in effluent	2.0 mg/l	1.4 mg/l
Average P removal	63.6 percent	83 percent
Average NO_3 in effluent	1.98 mg/l	0.2 mg/l
Average NO_3 removal	69.7 percent	61 percent

After 2500 BV had been processed by the replacement ion-exchange column preceded by the original sand filter, the sand filter was replaced. Table Six summarizes the system performance using the improved sand filter and ion-exchange equipment in processing the following 4000 BV. Also shown are the results previously obtained for a comparable period using the original sand filter and the original ion-exchange column. It can be seen that the improved equipment design produced a much increased efficiency of both phosphorous and nitrate removal, with effluent phosphorous content of 0.84 mg/l and effluent nitrate concentration of 0.73 mg/l. (Note: The apparent inconsistency of the nitrate figures is related to the widely varying degree of nitrification in the activated sludge unit. Operating difficulties at the Palo Alto Sewage Treatment Plant involving digestor supernatant return to the primary settling tanks has hindered the activated sludge nitrification periodically. This difficulty has now been overcome and consistent nitrification in the future is expected.)

TABLE SIX

	4000 BV processed* after first restoration, using original sand filter and original ion-exchange column.	4000 BV processed* after second restoration, using new sand filter and new ion-exchange column.	Amount of Improvement
Average P in effluent	2.49 mg/l	0.84 mg/l	1.65 mg/l
Average P reduction	56%	85.7%	29.7%
Average NO_3 in effluent	0.5 mg/l	0.73 mg/l	-0.23mg/l
Average NO_3 reduction	70%	79.1%	9.1%

* The 4000 BV referred to begins 2500 BV after restoration; i.e., the 2500 BV to 6500 BV operating results.

B. Diatomite Filtration

The major experiences and findings relative to diatomaceous earth filtration were as follow:

1. Diatomite filtration can without question greatly improve the quality of activated sludge effluent. Turbidity is reduced 80 to 90 percent, and suspended solids content is reduced by 78 to 87 percent as indicated by Table Seven. Figure Five shows that 90 percent of about fifty samples of diatomite filtered effluent had suspended solids content of less than six milligrams per liter.

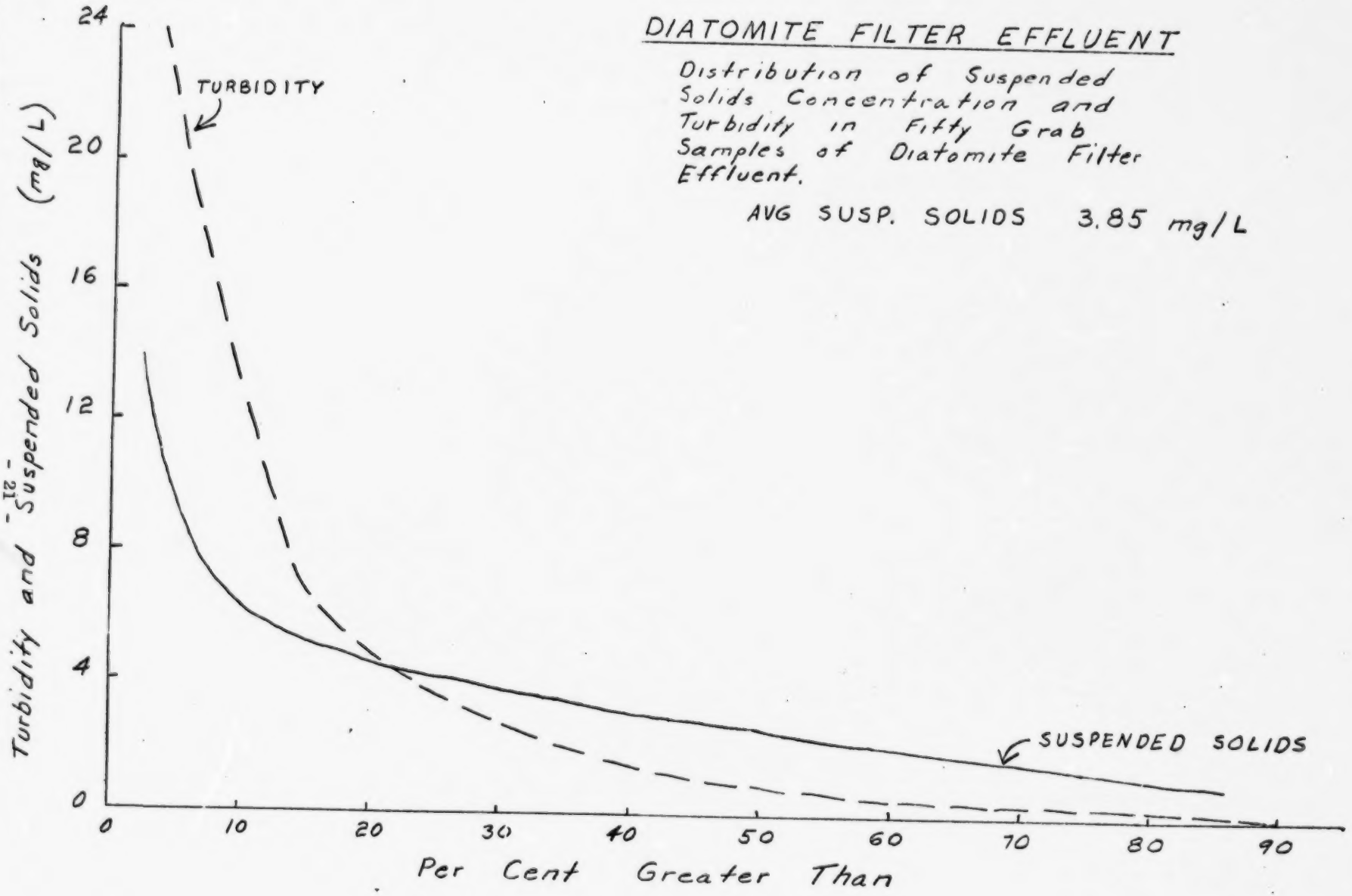

DIATOMITE FILTER EFFLUENT
Distribution of Suspended Solids Concentration and Turbidity in Fifty Grab Samples of Diatomite Filter Effluent.
AVG SUSP. SOLIDS 3.85 mg/L
TURBIDITY
SUSPENDED SOLIDS
Turbidity and Suspended Solids (mg/L)
Per Cent Greater Than
0
4
8
12
16
20
24
0
10
20
30
40
50
60
70
80
90

Figure Five

TABLE SEVEN

	Turbidity		Suspended Solids	
	No. of Samples	Average Conc.	No. of Samples	Average Conc. (mg/l)
A.S. effluent applied to D.E. filter (all runs)	39	21	64	30
D.E filter effluent (all runs)	47	4.3	49	3.8
Percent Reduction		79.5%		87.3%
For one particular run (October 21, 1965):				
Applied A.S effluent	13	10	15	18
D.E. filter effluent	15	1	14	4.0
Percent Reduction		90%		77.8%

2. The problem encountered with diatomite filtration of activated sludge effluent is well illustrated by Figures Six and Seven. Figure Six indicates the variability of of the instantaneous suspended solids content of activated sludge effluent. Despite the fact that the average suspended solids content of the 64 samples was 30 mg/l, it can be seen that the concentrations of 80 mg/l or greater were found about 10 percent of the time. The effect of this variation in quality is well illustrated by Figure Seven. When the diatomite filter is exposed to even a brief discharge of high-solids effluent, a permanent "blinding" of the filter results (as indicated

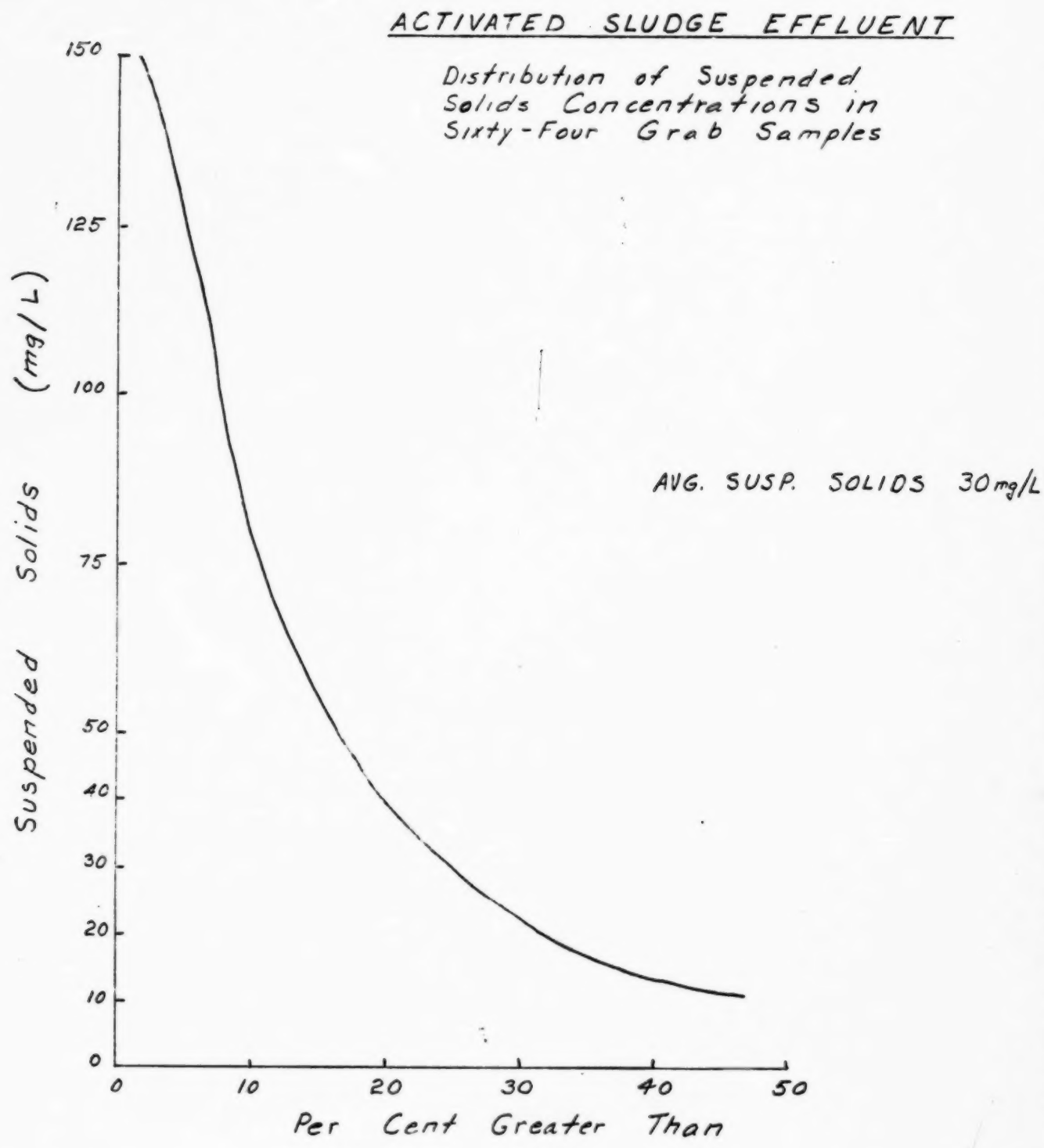
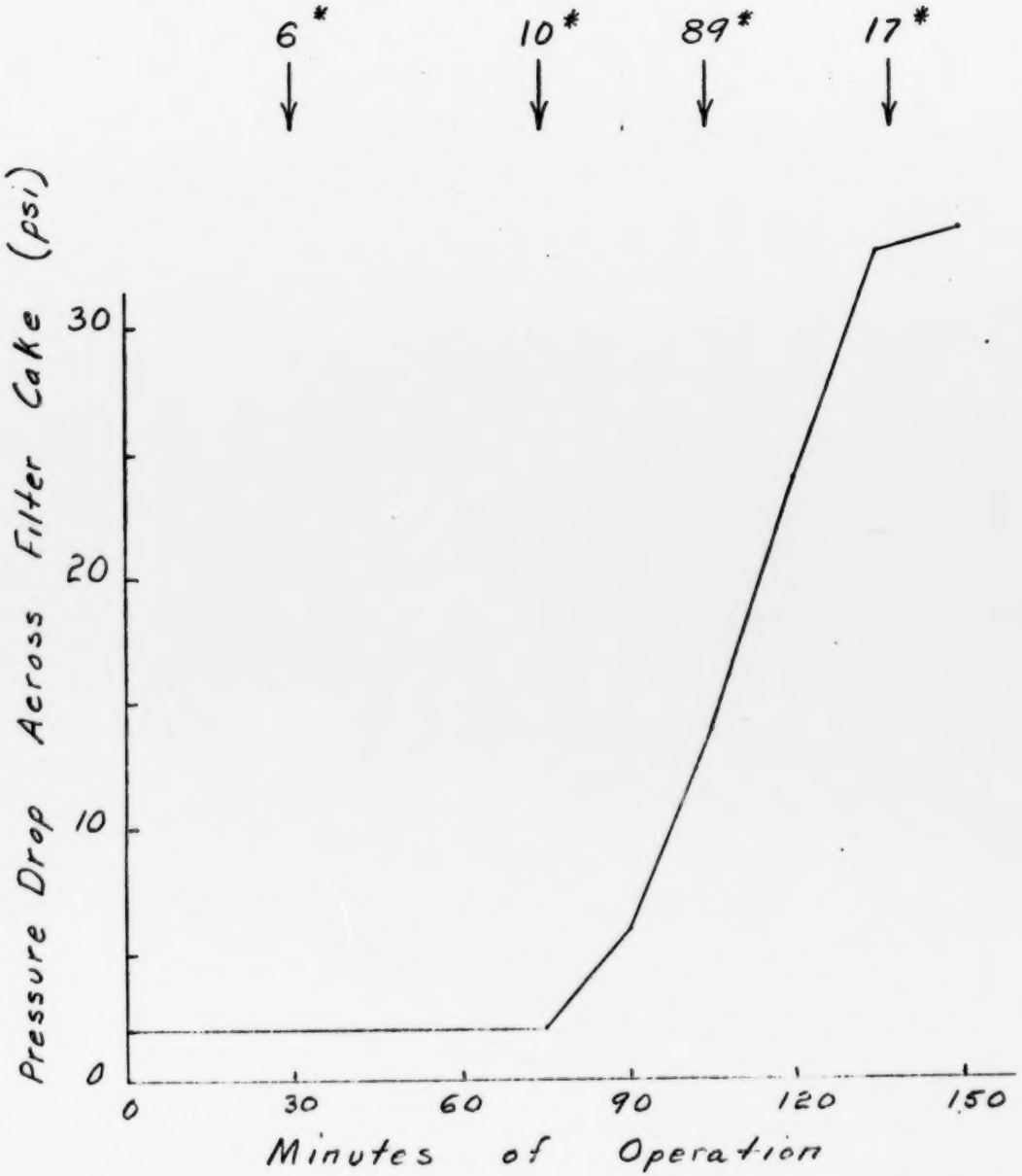

ACTIVATED SLUDGE EFFLUENT
Distribution of Suspended Solids Concentrations in Sixty-Four Grab Samples
AVG. SUSP. SOLIDS 30 mg/L
Suspended Solids (mg/L)
150
125
100
75
50
40
30
20
10
0
0
10
20
30
40
50
Per Cent Greater Than

Figure Six



DIATOMITE FILTER

Filter Cake Blinding
vs
Applied Water Quality

↓* - Indicates Suspended Solids content of applied activated sludge effluent.

Figure Seven

by cake pressure differentials of 20 psi or more, which caused the flow rate to diminish from 10 gpm to 3 gpm or less).

Diatomite filtration as a part of the demonstration plant treatment was therefore not feasible with the equipment on hand. It further seems reasonable to assume, since the activated sludge effluent at the demonstration plant is of good quality and representative of "normal" activated sludge effluents, that the problems encountered at the demonstration plant can be expected with most activated sludge effluents. It appears that, in order to take advantage of the extremely high quality filtration available through the use of diatomite filtration, it will be necessary to use some type of automatic feedback control device to measure the instantaneous effluent turbidity and adjust the body feed accordingly. Preliminary discussions have been held with equipment manufacturers, and it is hoped that arrangements can be made to obtain and test such a diatomite filtration system during the coming year.

C. Sand Filtration

Sand filtration difficulties with the original rapid sand filter involved the poor backwash water distribution system and the absence of surface wash provisions. Particulate matter accumulated both in the body of the media bed and at the sand surface, but the build-up of extraneous matter was particularly bad at the surface. "Mudball" formation was frequent, effluent quality was poor, and head loss through the filter was unnecessarily high. It can be seen from Table Eight that proper filter design significantly improved sand filtration effectiveness, the percentage removal of Suspended Solids being more than doubled (21% versus 52%). The result of this improved filtration with respect to ion-exchange effectiveness has been previously noted in this report.

TABLE EIGHT

Relative Filter Effectiveness:

	Applied SS	Effluent SS	Reduction
Diatomite Filter	18 mg/l	4 mg/l	78%
Original Sand Filter (no surface wash)	16 mg/l	12.6 mg/l	21%
Improved Sand Filter	17 mg/l	8.2 mg/l	52%

D. Economic Considerations

The previous progress report presented estimated costs for ion-exchange water renovation. Experiences and observation at the demonstration plant during the past year indicate a number of areas where the initial estimated costs may be reduced or eliminated. Table Nine presents the original and the revised cost estimates. The major areas where prior estimates have proved conservative involve restoration chemicals and capital equipment. Table Ten illustrates the basis for estimating the restoration costs at a lesser figure. It can be seen that a 50 percent reduction in the amount of acid-methanol used had no appreciable effect upon the degree of restoration, and that reducing the restorant chemicals by 71.5 percent still restored an appreciable amount of fouled resin capacity. The reduction in estimated capital recovery costs is based primarily upon the equal or better resin performance recently achieved at higher flow rates (26 BV per minute versus 10 BV per minute) and on the use of rapid sand filtration instead of diatomaceous earth filtration. Bentonite costs have been eliminated and hydrochloric acid costs increased slightly. The bentonite was originally intended to be used to combat physical fouling of the resin by scouring off agglomerated

TABLE NINE

ESTIMATED AND REVISED COSTS OF ION-EXCHANGE WATER RENOVATION

Item	Original Estimate Costs - cents/1000 Gal.	Revised Estimate Costs - cents/1000 Gal.
Resin Replacement	2.75	2.75
Salt	3.58	3.58
Bentomite	0.10	-
Methanol	2.50	1.00 to 1.75
Hydrochloric Acid	0.13	0.19 to 0.25
Sodium Hydroxide	0.09	0.00 to 0.09
Diatomaceous earth	0.52	-
Sub-total:	9.67	$ 7.52 to 8.42
Labor and Overhead	6.60	6.60
Power	1.43	1.43
Capital Recovery Costs	3.05	1.55 to 2.30
Total:	20.75	$ 17.10 to 18.75

TABLE TEN

RELATIVE RESTORATION DOSES AND COSTS

10 BV of Acid-Methanol — Chemical Cost 2.63 cents per 1000 gals.

	First 150 BV		150-180 BV		Overall Removal	
	Effl. (mg/l)	Percent Reduction	Effl. (mg/l)	Percent Reduction	Effl. (mg/l)	Percent Reduction
P	0.21	97%	1.75	73.5%	0.47	92.9%
NO_3	0.23	98%	1.05	91%	0.37	96.9%
ABS	0.15	73%	0.25	54.5%	0.17	70%
COD	27	40%	32	29%	28	38%

5 BV of Acid-Methanol — Chemical Cost 1.32 cents per 1000 gals.

	Effl. Conc. (mg/l)	Percent Reduction	Effl. Conc. (mg/l)	Percent Reduction	Effl. Conc. (mg/l)	Percent Reduction
P	0.42	93.5%	1.9	71%	0.68	89.7%
NO_3	0.33	97.2%	1.56	87%	0.54	95.5%
ABS	0.2	63.5%	0.3	45.5%	0.22	60%
COD	32	29%	32	29%	32	29%

2.86 BV of Acid-Methanol — Chemical Cost 0.75 cents per 1000 gals.

	Effl. Conc. (mg/l)	Percent Reduction	Effl. Conc. (mg/l)	Percent Reduction	Effl. Conc. (mg/l)	Percent Reduction
P	0.68	90%	3.76	43%	1.19	82%
NO_3	0.77	93.5%	3.48	71%	1.22	89.7%
ABS	0.25	54.5%	0.35	36%	0.27	51%
COD	32	29%	36	20%	33	23.5%

Resin Performance Prior to Restoration Treatments

	Average mg/l in Effluent	Average Percent Reduction
P	5.2	45%
NO_3	1.8	89%
ABS	0.8	58%
COD	16	33%

material from the resin beads; it has since been established that a rinse with an 0.8 N solution of hydrochloric acid is more effective in resin cleaning.

E. Ion-Exchange Application

The applicability of ion-exchange for water renovation purposes will vary according to the particular situation in question, particularly with respect to the characteristics of the potable water and the relative importance of "trace" nutrients (nutrient materials other than nitrogen and phosphorous).

A major consideration in determining whether ion-exchange is the most appropriate method of nutrient removal and water renovation will be the chloride content of the effluent produced by conventional sewage treatment. It is clear from Table Eleven that the relatively high chloride content of Palo Alto sewage has a significant effect upon the nutrient removals achieved at the demonstration plant. The high removals which have been obtained since the improvement of the demonstration plant equipment would obviously be even better if the chloride content of less than 25 mg/l. Since the normal increase in chlorides during one cycle of use (supplied potable water quality versus sewage plant influent quality for a given city or area) is on the order of 20-50 mg/l, an area or city utilizing Hetch Hetchy water could expect to receive even greater efficiency of treatment at lower costs than those given in Table Nine. Conversely the use of a high chloride content (300 mg/l or more) water as the potable water supply in an area would be a detrimental factor in considering water renovation via ion-exchange. From this standpoint, it is significant and encouraging that satisfactory demonstration plant results are being obtained using a relatively high-chloride water, since areas with a more normal chloride content can expect to receive treatment efficiencies even higher than those achieved at Palo Alto.

TABLE ELEVEN

EFFECT OF WASTE WATER CHLORIDE CONTENT

COLUMN 1 - Normal Palo Alto Wastewater
Chloride = 212 mg/l

	Influent Conc.	Effluent Conc.	Percent Reduction
P	4.0 mg/l	0.83 mg/l	79.3%
NO_3	11.4 mg/l	1.06 mg/l	90.7%
ABS	0.55 mg/l	0.2 mg/l	63.6%
COD	45 mg/l	32 mg/l	29 %

COLUMN 2 - Normal Palo Alto Wastewater Diluted, with P and NO_3 Added
Chloride = 118 mg/l

	Influent Conc.	Effluent Conc.	Percent Reduction
P	5.12 mg/l	0.19 mg/l	93.6%
NO_3	14.6 mg/l	0.24 mg/l	98.4%
ABS	0.33 mg/l	0.13 mg/l	60.6%
COD	22.5 mg/l	18 mg/l	20%

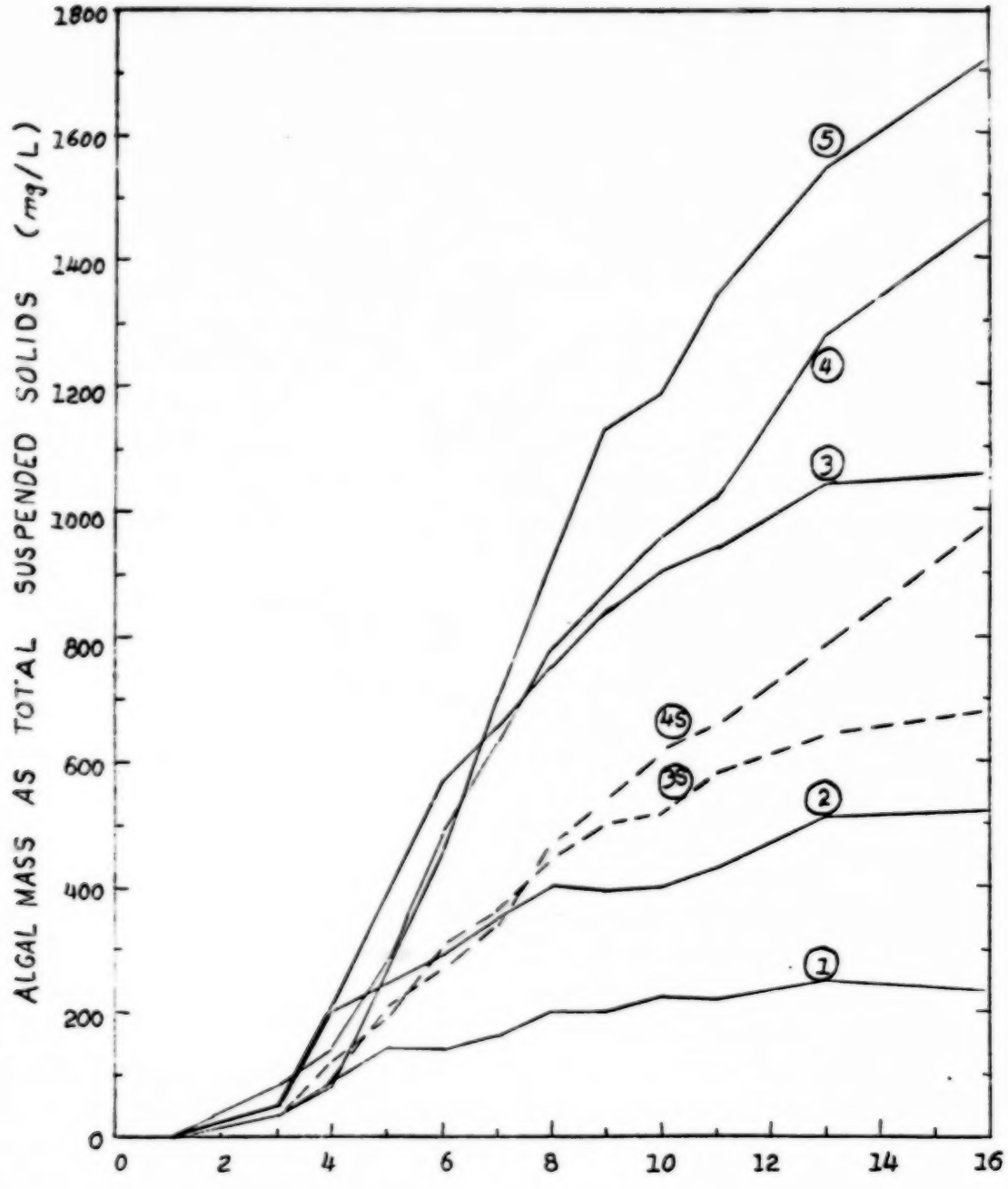
COLUMN 3 - Diluted Palo Alto Waste Water, with P and NO_3 Added
Chloride = 58.5 mg/l

	Influent Conc.	Effluent Conc.	Percent Reduction
P	4.36 mg/l	0.1 mg/l	97.7%
NO_3	6.75 mg/l	0.19 mg/l	97.2%
ABS	0.13 mg/l	0.05 mg/l	61.5%
COD	18 mg/l	9 mg/l	50 %

F. Algal Growth Studies

Since nutrient removal is intended primarily to limit and control the growth of algae, it was deemed advisable to investigate the effects of ion-exchange nutrient removal upon algal growth. Figure Eight and Table Twelve refer to continuous-light, accelerated growth studies and indicate clearly that algal growth is related to the degree of ion-exchange treatment involved. Lines 2, 3, and 4 on Figure Eight refer to various mixtures of ion-exchange effluent and influent while lines 1 and 5 refer to 100 percent ion-exchange effluent and 100 percent ion-exchange influent, respectively. It can be seen that after 16 days exposure to light, about eight times more algal growth occurred in the ion-exchange influent than could be produced in the effluent. Treating one-half of the activated sludge effluent with ion-exchange reduced algal growth by about 40 percent.

Lines 1 and 5 of Figure Eight have particular significance. It is reasonable to expect that the extreme difference in the amount of growth produced under ideal conditions may be even more pronounced in the natural setting. This is because of the mitigating factors such as fish life, light availability, pH effects which tend to limit algal growth and destroy algae in a "natural" way. Growth such as obtained in ion-exchange effluent (line 1) would probably present no problem since the "natural" inhibiting factors in the environment would be able to keep pace with, and thereby effectively control, algal growth. On the other hand, it is quite likely that the growth potential indicated by line 5 (filtered activated sludge effluent) would result in such a rapid increase in algal mass that "natural" control factors would be unable to sufficiently control the algae, with the result that an algal bloom would occur. This line of reasoning suggests a sensible rationale to the question of algae problems. It would seem useful to approach algae control from the viewpoint that in a high nutrient environment algae will flourish and eventually dominate the environment, while in a low or normal nutrient situation, the environment will control the algae.



ALGAL GROWTH WITH TIME

Figure Eight

TABLE TWELVE

ALGAL GROWTH STUDIES

Sample Number	Description	Nutrient Concentration (mg/l) Nutrient Form	Original in Sample
1	Ion-Exchange Effluent	NH_3-N	3.78
		NO_3-N	0.3
		Ortho-P	0.28
		Poly-P	0.95
2	80% Ion-Exchange Effluent and 20% Ion-Exchange Influent	NH_3-N	3.80
		NO_3-N	6.2
		Ortho-P	3.5
		Poly-P	2.0
3	50% Ion-Exchange Effluent and 50% Ion-Exchange Influent	NH_3-N	3.80
		NO_3-N	15.0
		Ortho-P	8.2
		Poly-P	3.4
4	20% Ion-Exchange Effluent and 90% Ion-Exchange Influent	NH_3-N	3.80
		NO_3-N	23.7
		Ortho-P	13.0
		Poly-P	4.9
5	Ion-Exchange Influent	NH_3-N	3.86
		NO_3-N	29.6
		Ortho-P	16.2
		Poly-P	5.9

With regard to the question of inhibiting algae growth per se, via nutrient removal, lines 3S and 4S indicate that ion-exchange treatement can and does provide benefits in excess of those accruing to the removal of phosphorous and nitrates. It can further be seen that when the beneficial effects of P and NO_3 removal are eliminated by replacing the amounts of these nutrients removed by ion-exchange treatment (Table Thirteen), algae growth is still significantly inhibited. The inhibitory effect is apparently due to the removal of other "trace" nutrients by ion-exchange. It has been well recognized that removal of COD and ABS is an incidental benefit in improving water quality during ion-exchange renovation, but heretofore the beneficial effects of ion-exchange relative to trace nutrients has been less clearly defined.

TABLE THIRTEEN

TRACE NUTRIENT TEST WATERS

Sample Number	Description	Nutrient Concentration (mg/l)			
		Nutrient Form	Original in Ion-Exchange Effluent	Synthetic Added	Total
3S	Ion Exchange Effluent	NH_3-N	3.78	-	3.78
		NO_3-N	0.3	14.7	15.0
		Ortho-P	0.28	7.9	8.2
		Poly-P	0.95	-	0.95
4S	Ion Exchange Effluent	NH_3-N	3.78	-	3.78
		NO_3-N	0.3	23.4	23.7
		Ortho-P	0.28	12.7	13.0
		Poly-P	0.95	-	0.95

GENERAL CONCLUSIONS

The general conclusions which may be drawn from operating experience and investigations conducted during the past eleven months include the following:

1. Proper equipment design is a key factor in the successful application of filtration and ion-exchange techniques to water renovation.

2. Sustained removals of phosphorous and nitrates on the order of 85.7 percent and 79.1 percent respectively (corresponding to effluent concentrations of 0.84 mg/l for P, and 0.73 mg/l for NO_3) can be achieved.

3. Essentially complete restoration of fouled resin capacity is feasible, as illustrated by Figures 3 and 4 , which indicate the effectiveness of restoration treatments done in the course of demonstration plant operation.

4. Restoration treatment chemical costs can be significantly reduced. (Tables Nine and Ten).

5. Ion-exchange equipment costs can be greatly reduced due to the ability of the ion-exchange resin to operate at 2.6 times the flow rate previously assumed.

6. Rapid sand filtration, while not producing as high quality an effluent as diatomite filtration, can nonetheless be effectively used with ion-exchange treatment.

7. Diatomite filtration of activated sludge requires some means of adjusting the body feed rate in proportion to the varying quality of the sewage treatment effluent water.

8. Non-nutrient anions, particularly chlorides, will be an important factor in deciding the applicability of ion-exchange techniques for any particular situation.

9. There are definite and demonstrable benefits of ion-exchange treatment relative to algal growth which are separate from and not related to the removal of phosphorous and nitrates.

FUTURE OBJECTIVES

Objectives in the immediate future will be as follows:

1. To continue to operate the demonstration plant on a routine basis and further define the characteristics, advantages, and limitations of filtration and ion-exchange techniques in the renovation of watewater.

2. To optimize chemical dosages and operational techniques, with particular emphasis upon restoration treatment costs and the effects of ancillary treatment unit efficiencies.

3. To explore in depth the parameters, implications, and potential benefits accruing to filtration of sewage treatment effluents, both in the context of ion-exchange renovation, and also as an independent means of effluent quality improvement.

4. To continue to explore the applicability of ion-exchange techniques, relative to varying effluent quality characteristics.

5. To continue to investigate and define the effects of ion-exchange treatment relative to algae growth in the receiving waters, considering phosphorous and nitrate removal effects, and also the effect of trace nutrient removal.

6. To attempt to obtain and operate a diatomaceous earth filter suitable for filtration of activated sludge effluents.

7. To determine the control and quality implications of turbidity information, relative to water renovation.

8. To initiate and complete a comprehensive evaluation of virus removal effects of filtration and ion-exchange treatments, both collectively and individually.

REPORTS AND ARTICLES

A paper entitled "Removal of Nutrients from Wastewaters Using Filtration and Ion-Exchange Methods" is currently in preparation. It is being co-authored by Dr. Rolf Eliassen and George Bennett and will be presented at the 39th Annual Water Pollution Control Federation Conference at Kansas City Missouri, on September 29, 1966.

The last previous progress report, covering the period of July 17, 1964 to September 14, 1965 has been published and distributed as Technical Report No. 58, Department of Civil Engineering, Stanford University.

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PROFESSIONAL STAFF

1. Project Director - Dr. Rolf Eliassen, Professor of Sanitary Engineering, Stanford University.

   Professor Eliassen has been with the project since its inception and has spent about ten percent of his time on the project. Biographical data were included in the original application.

2. Dr. Perry L. McCarty, Associate Professor of Sanitary Engineering, Stanford University.

   Professor McCarty has been with the project since its inception and has spent about ten percent of his time on the project. Biographical data were included in the original application.

3. George E. Bennett, Research Engineer, Stanford University. Mr Bennett joined the project on August 23, 1965 and has spent 100 percent of his time on the project. Biographical data were included in the previous progress report.